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Spatial and Temporal Variation in Water Quality along an Urban Stretch of the Chattahoochee River and Proctor Creek in Atlanta, GA, 2014

Dominique Smith

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by

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ABSTRACT

Dominique Smith
Spatial and Temporal Variations in Water Quality Along an Urban Stretch of the Chattahoochee River and Proctor Creek in Atlanta, Georgia, 2014
(Under the direction of Dr. Lisa Casanova, Faculty Member)

Urban development and increased impervious surfaces have contributed to pollution loading in the Chattahoochee River and Proctor Creek, major urban waterways and receiving waters for Atlanta stormwater and wastewater effluent.

The purpose of this study was to investigate spatial and temporal variation in *E. coli* and bacteriophage MS2 and relationships with Dissolved Oxygen, turbidity, rainfall, and riverflow; and to determine if wastewater effluent discharge points in the river influence bacterial levels. During a five-month period, water samples were collected at fifteen sample sites and two outfall sites in the Chattahoochee River, and five Proctor Creek sites. No significant spatial variation in mean *E. coli* concentration was found for the Chattahoochee and concentrations of bacteria were not significantly different upstream and downstream of wastewater effluent outfalls. However, there was significant temporal variation in mean *E. coli* concentrations for the Chattahoochee River ($p < 0.0001$) and Proctor Creek.

These findings indicate that *E. coli* and MS2 are commonly present in the river across wide spatial and time scales, possibly due to nonpoint source pollution.

Index Words: *E. coli*, MS2, Dissolved Oxygen, Turbidity, Chattahoochee River, Proctor Creek

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Lastly, I would like to give special thanks to the Chattahoochee Riverkeeper and the West Atlanta Watershed for your continuous efforts to improve and maintain the water quality of the Chattahoochee River and surrounding tributaries, as well as your willingness to help with the collection of samples that made this research project possible.

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___Dominique Smith___

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CHAPTER I

INTRODUCTION

1.1 Background

The Chattahoochee River is an integral facet of the state of Georgia and City of Atlanta, as it is the most utilized surface water source for drinking water of the state, providing more than seventy percent of Metro-Atlanta's water needs (EPD, 1997). The 434-mile long river flows through Georgia, metropolitan Atlanta, and Alabama before terminating in Florida's Lake Seminole (EPD, 1997). In addition to being a surface water source, the Chattahoochee River also assimilates a large amount of metro Atlanta's municipal wastewater discharge (EPD, 1997). Proctor Creek, another urban surface water, is a tributary of the Chattahoochee River located in western Atlanta. Small streams at the Atlanta University Center converge to form Proctor Creek and it then flows through the English Avenue, Vine City, Mozley Park, West Highlands and Bankhead neighborhoods (DWM, 2015). Proctor Creek, stretching northwest for nine miles, is the only major watershed located entirely within the Atlanta city limits before being deposited into the Chattahoochee River south of the Interstate 285 Bridge, near Whittier Mill Village (DWM, 2015). Proctor Creek water quality is important as it receives water from multiple stormwater outfalls (EPA, 2003). Therefore, Atlanta's reliance on the Chattahoochee River and Proctor Creek necessitates monitoring and maintaining the integrity of these surface waters.

The city of Atlanta has experienced steady population growth with a population burst beginning in 1990 (ARC, 2013). The 10-county Atlanta region added approximately 40,100 people between April 1, 2012 and April 1, 2013, averaging an annual growth of 37,283 since 2010 (ARC, 2013). With the influx in residents, the amount of sanitary sewage in the system increased correspondingly. However, Atlanta's sewer system was built in the 1880s and has issues with cracked and leaking pipes that were not built to handle the increase in volume from the city's sanitary sewage (Clean Water Atlanta, 2010). The population increase has resulted in a built environment that is replacing green space with impervious surfaces to accommodate the new inhabitants, thus producing a tremendous increase in the amount of storm water runoff, of which the system was not intended to accommodate. Consequentially, the sanitary sewer system becomes overwrought, leading to sanitary sewer overflow (SSO) events, during which a mixture of groundwater, untreated sewage, and stormwater overflow from pipes and manholes, many of which are located within close proximity to streams and creeks (Clean Water Atlanta, 2010; Perkins, 2014).

Due to the aforementioned reasons, such as sewer overflows, inadequate collection capacity, and high bacterial levels in waterways, the city of Atlanta was sued for violating the Clean Water Act in 1995 (EPA, 1999). In response several state and federal laws, such as the Federal Clean Water Act, Safe Drinking Water Act, and the State Water Quality Control Act were instated to protect the Chattahoochee River's water quality by defining and monitoring definitive water quality standards for the health of the public (EPD, 1997). One of the outcomes of this case was the creation of the Consent Decree, which had the objective of improving the cities four Water Reclamation Centers (WRCs) in order to comply with state regulations and legislative mandates set by the aforementioned laws. Specifically, the Consent Decree was intended to improve the water quality in the receiving waters downstream, such as the Chattahoochee, by improving the water quality of the effluent discharged from the WRCs (Clean Water Atlanta, 2010).

To address the issues caused by SSO the Environmental Protection Agency (EPA), the Environmental Protection Division of the State of Georgia (EPD), and the City of Atlanta negotiated a settlement entitled the First Amended Consent Decree (FACD). Approved in 2003, the FACD evaluated and improved measures to eliminate SSOs and upgrade WRCs to ultimately eliminate groundwater and stormwater entering the system entirely. Building on current city programs, FACD intensifies review of building permit applications that propose adding new flows into the sewer system, uses closed-circuit television to inspect and assess the condition of sewers, and manages plans to operate the collection system more efficiently (Clean Water Atlanta, 2010). The FACD established plans to increase the city's total separation area from 85% to 90%, to eliminate two Combined Sewer facilities, and construct a deep rock tunnel storage and treatment system. The system captures and stores combined stormwater and sewage flow for conveyance to two new Combined Sewer Overflow (CSO) treatment facilities before discharge into the Chattahoochee. Successful implementation should reduce more than sixty annual CSO events at six existing facilities to an average of four annually at four remaining facilities (Clean Water Atlanta, 2010). All remaining overflows will be screened, disinfected, and dechlorinated according to water quality standards before discharged into the Chattahoochee River.

Proctor Creek has also experienced water quality degradation, resulting in the City of Atlanta and other organizations stepping in to address the creek's issues. Decades ago, the creek used to serve the community as a place to play, fish, and was even used as a baptismal pool; however, years of illegal dumping, pollution, and erosion have resulted in high bacteria levels in Proctor Creek (Wheatley, 2013). In fact, the creek is among 11 streams added to the EPA's federal program, Urban Waters Federal Partnership, which intends to restore waterways in urban areas. In 2013, thirteen federal agencies began collaboration to promote more efficient and effective uses of federal resources by improved coordination and targeting of federal investments (EPA, 2013). Another component of the partnership is to engage and serve the community in which the waterway is located by building on local efforts and leadership. The Urban Waters Federal Partnership joined the Chattahoochee Riverkeeper and West Atlanta Watershed Alliance to aid the locally based organizations in expanding their programs such as, the Neighborhood Water Watch program, water conservation initiatives, and creek clean-ups in some of the poorest and most polluted areas of the watershed (EPA, 2013). Many eyes are on Proctor Creek, expecting advances in improved water quality for the creek so monitoring of the waterway is critical.

Implementation of the federal and state laws previously mentioned are improving the health of the Chattahoochee and surrounding tributaries. The water quality of the Chattahoochee River basin is currently considered to be generally good since wastewater discharges have been strictly controlled (AJC, 2014; EPD, 1997). Nevertheless determining the current factors influencing water quality is critical. Much advancement have been made to reverse the effects of point source pollution affecting the Chattahoochee River, but today nonpoint source pollution is the leading contributor of contaminant loading. Although Metro-Atlanta may seem well developed, the loss of green space is still occurring at drastic rates, in fact, it was reported that Atlanta losses 500 acres of open space to development each week (Conservation Fund, 2015). As the city continues to grow and the amount of impervious surface increases, more stormwater runoff will make its way into key Atlanta watersheds during rain events.

The runoff that accumulates during rain events can transport bacterial contaminants to watersheds. Past studies examining the variations in microbial water quality have focused on wet, rainy seasons to determine the amounts of contaminants in waterways are related to the high rainfall (Huang, et al., 2011, Boyacioglu, 2010). Previous studies have found water quality degradation can be attributed to recent flood events that cause stormwater runoff, dissolution, and resuspension of deposits, significantly increasing pollutant load (Maane-Messai et al., 2010). Summer 2014 was fairly dry compared to the previous summer, which experienced a record-breaking amount of rainfall, making 2013 the fifth wettest year on record with a total rainfall of 66.02 inches (Perkins, 2014). The National Weather Service Forecast Office calculated the summer (May-September) rain score for 2013 to be 36.8, more than fifteen points over the thirty-year average rainfall score for Atlanta. Summer 2014 was scored below the average thirty-year average at 18.54 (NOAA, 2015). These stark differences in climate will shed light on links in water quality and below average rainfall score.

1.2 Purpose of the Study

Fecal-coliform bacteria is a type of microbial bacteria that exists in the intestines of warm-blooded animals and if found in a body of water, often indicates fecal contamination. *Escherichia coli*, a type of fecal-coliform bacteria, is an indicator of microbial pollution in water sources but using *E. coli* as the sole fecal indicator bacteria (FIB) in water quality monitoring may not detect viral contamination sufficiently. Therefore a bacteriophage linked to wastewater samples called MS2 can reflect the impact of urbanization on surface water samples (Cole, Long, & Sobsey, 2003). Secondly, *E. coli* and MS2 spatial variation along rivers and creeks is beneficial in determining sources of fecal pollution. Also, temporal variations are often a result of changes in climate; such are rain events, temperature, and river flow. Furthermore, temporal variations can also be indirectly affected by increased recreational activities and wastewater effluent discharges. Lastly, although they have been recently identified as waterways of interest by local, state, and federal entities, few investigations have been published concerning the water quality of the Chattahoochee River and Proctor Creek.

1.3 Research Questions

The specific research questions to be analyzed in this study are as follows:

- Are there spatial and temporal variations in *E. coli* concentrations along the Chattahoochee River and the Proctor Creek sample sites?
- Are the concentrations of *E. coli* correlated with dissolved oxygen (DO), turbidity, and riverflow?
- Are the concentrations of *E. coli* correlated with the presence of MS2?
- Does the discharge of effluent from the Camp Creek Outfall and the Douglas County Outfall into the Chattahoochee River affect the concentrations of *E. coli* downstream?

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Spatiotemporal Variation from Urbanization and Pollution

Urban Environment

The surface water of a given area is the lifeblood of the community. For this reason various studies have been conducted to determine the specific ways humans affect the quality of water in urban areas and to identify significant trends that will allow researchers to predict the concentration of certain contaminants. The natural resource is often collected from ground and surface water, treated through various filtration methods (either via private and public wells, municipal water treatment plants, and bottling factories) and supplied to the public, but the process water undergoes to reach the consumer does not solely affect those on the receiving end of the drinkable water course. At every step, environmental and natural processes are altered to support the development of the human community, especially so in urban areas where numbers of human density are increasing exponentially (Oiste, 2014).

Many studies focus on the effects of urbanization on the quality of water resulting in combined sewer overflows (CSOs), non-point and point pollution, runoff, discharges and a number of additional factors that alter the composition of water bodies (Oiste, 2014; Heisler et al., 2010; Peters, 2009). According to Boyacioglu and Boyacioglu, rivers are the most vulnerable water bodies due to their easy accessibility for domestic, industrial, and agricultural discharges like the aforementioned factors in deficient water quality (2010). In urban areas in particular, where many people inhabit a small space, finding the culprits of pollution is all the more difficult. The Hau City River and Mekong River basin are examples of two well-known rivers that are frequently used for commercial and recreational purposes (such as fishing, transportation, swimming, and bathing), which makes adequate water quality critical to the health of the public and the ecosystem but also difficult to enforce due to the high population density surrounding the Vietnamese cities (Ozaki et al, 2014).

A recent study in Atlanta, Georgia focuses on the effects urbanization has on the water quality of streams in the metropolitan area, finding that urban development has the ability to change the natural flow and pathways of water bodies (Peters, 2009). This is evident in the ways that cities in the U.S. have traditionally been built. A recent study analyzing 20 different cities, conducted by Nowak and Greenfield, reports that urban tree cover (the proportion of area, when viewed from above, occupied by tree crowns) is reducing by an average of 0.27 percent annually while impervious surfaces are increasing at an average rate of 0.31 percent a year (Nowak & Greenfield, 2012; Nowak et al, 1996). This research provides evidence of the phenomenon that is apparent to city dwellers: cement is replacing green space in many parts of the world and denser population often results in a decline in natural environments. Conversely, industrial development can improve the quality of life for many, as it provides convenience in transportation, increased employment opportunities, and access to resources that are not as easily accessed in rural communities (Sallis, 2009). Yet, along with all the benefits humans receive from residing in cities, the human presence can also pose a great threat to the natural balance. Increased impervious surfaces (artificial structures covered by impenetrable materials such as asphalt, concrete, brick, and stone) swell local temperatures and urban heat islands (phenomenon in which cities are generally warmer than nearby rural areas), consequently affecting building energy use, human comfort and health, ozone production, and most significantly urban hydrology (US EPA, 1983; Heisler and Brazel, 2010; US EPA, 2015; National Research Council, 2008; Nowak and Greenfield, 2012).

The article by Perkins (2014) refers to the Brion et al. study that determined areas of urban activity were more likely to recover F+ phages during rainfall events compared to agricultural sites (Brion, Meschke, & Sobsey, 2002). The studies in this area point to the relationship between urbanization and an increase in contaminant concentrations, with a stronger correlation occurring after a rain event. This may be attributable to the amount of impervious surface that does not allow water to seep into the ground and be filtered throughout layers of soil. Instead of percolating through earth to become groundwater, precipitation becomes runoff that flows down the watershed to the lowest point, creating streams and creeks, which flow into rivers. However, since the water path flows throughout a city, it can pick up sediment, oil from roads, bacteria, and a host of other substances that will be deposited into the surface water it travels to. A tidal creek study supports this idea with the findings that concentrations of indicator microorganisms were the highest in more developed watersheds while fecal coliform concentrations were significantly lower in forested creeks compared to urban and suburban creeks (DiDonato et al., 2009).

Spatiotemporal Variation

The changes in contaminant concentration, although seemingly arbitrary, have been found by research to follow certain trends based on the location and time the water sample was collected. A study on coastal water quality in Macau, China found significant variations in spatiotemporal water quality in the 22 monitoring sites near overflow manholes and sewer pipes (Huang et al. 2011). Group B, which consisted of sites in western Macau peninsula, not near open coastal water, had poorer water quality compared to Group A. The researchers attributed this difference to domestic wastewater from untreated or overflow sewer pipes, which were a major source of pollution in the Group B monitoring sites.

Monitoring sites during different periods of time can render information about water quality trends. From previous research, seasonal changes greatly influences the temperature of water bodies, which in turn changes the make up of key water quality parameters (Keery et al., 2007). When identifying variations in temporal concentrations of Macau, a significant pattern was found when the months June, July, August, and September were clustered together categorically as the wet months and the rest of the year clustered as the dry season. Had Huang et al. empirically divided the data into groups based on seasons spring (March-May), summer (June-September), autumn (October-December), and winter (January-February) a grouping mistake would have been made since the Macau peninsula does not align with the traditional four seasons. This study supports the importance of knowing the weather patterns of a given location to approach analysis of temporal changes. Temporal variations were the focus of another study in India, specifically along the Gomti River (Singh et al., 2004). The major Ganga River tributary was monitored at eight sites selected in regions of various pollution levels ranging from low, moderate, to high for five years (1994-1998). The Gomti River was tested for twenty-four parameters and in the five years of testing in the eight locations, 17,790 observations were captured. Using multivariate techniques to analyze the data, researchers found that all twenty-four parameters are significantly correlated with the season, except for BOD, K, NH4-N, and TKN. Temperature exhibited the highest correlation coefficient (Spearman's R=0.71) with the season. The researchers suggested that the parameters not correlated with the season indicated contributions of anthropogenic sources.

Collecting samples from various locations throughout a water body can expose potential pollution sources, providing evidence for the necessity of remediation process initiation, by identifying spaces where the body of water is compromised. From 1993-2002 the 470 km Han River in the Korean Peninsula was monitored in twenty-six different stations and tested for eight parameters (water temperature, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, suspended solid, total nitrogen and total phosphorus) (Chang, 2005). More than 23 million people utilized the river for drinking, navigation, irrigation, and recreation but water quality had been on a gradual decline since the 1960s according to the Ministry of Environmental Republic of Korea (2003). To discover what was causing contaminated fish with deformed bones in the lower part of the main river, researchers examined water quality measurements and found that quality of water declined dramatically in the middle section of the Han River where inputs from polluted tributaries are received. All the water quality measurements declined between the Main River Station three (M3) and Main River Station six (M6), which were located downstream. The scattering of sites along various sections of the river allowed the researchers to discover the trends in given parameters leading them to recognize the tributaries as the source of a large amount of river pollution downstream. The spatial variation examination also brought Chang to detect the combined sewer systems as another pollution source for the river and its tributaries. Since a majority of Seoul's sewage systems are combined sewer systems (88%) that collect and treat rain and waste water together without separating them, during a rain event, environmental contamination of untreated wastewater overflows occur. Although Atlanta has had mostly separated sewer systems for over a decade, overflows are still common as many sewer pipes are aged, resulting in frequent clogs and sewage pipe manhole bursts (Clean Water Atlanta, 2013).

2.2 Weather-Related Events and Stormwater Runoff

Both combined sewer systems and separate sewer systems are known for their tendency to overflow during rain events, discharging volumes of wastewater and surface water into watersheds (Lee and Bang, 2000, Balmforth, 1990, Lee et al. 1996). However, combined sewer overflows (CSO) are more commonly held responsible for the deterioration of receiving waters, as more pollutants are likely to flow into the watersheds of the area CSSs are serving. Suarez and Puertas clarified the differences between the types of wet weather pollutant sources, stating CSO discharges consist of a mixture of industrial wastewater, urban surface runoff, domestic wastewater and sewer deposits that are discharged into receiving waters. While discharges from separated systems are mainly composed of urban surface runoff (Suarez and Puertas, 2004). From this comparison, the reason combined sewer systems receive the blame for a majority of weather related pollution of waterways is clear, and possibly warranted.

Combined sewer systems can spew the waste separated systems discharge in addition to waste from a host of other sources; however, surface runoff is not harmless, especially the runoff accumulated in urban areas. Nonpoint pollution is identified as one of the major causes of poor quality of receiving waters. But researchers Lee and Bang discovered which type of land use area caused the worst pollution drainage, their study correlated high density residential communities with higher levels of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS), total Kjeldahl nitrogen (TKN), nitrate–nitrogen (NO_3–N), orthophosphorus (PO_4–P), total phosphorus (TP), n-Hexane extracts, lead (Pb) and iron (Fe) (2000). To give an idea of the amounts of certain contaminants are coming from run off, in 2005, Chang stated that 70% of total suspended solids and 80% of total phosphorus input are attributable to nonpoint pollution (Choi et al., 1994, Kim and Choi, 1996).

Since urban surface runoff, CSOs, and SSOs are all dependent on the amount of rainfall, weather pattern trends are important for researchers to monitor as previous research supports the suggestion that more rainfall will result in more contaminated runoff into watersheds whether that area is serviced by a CSS or SSS. The Santa Monica Bay beach water is so affected by rainfall induced urban runoff that county health departments typically issue warnings for the public to avoid recreational water contact for 3 days post storm event, when levels returned below state water quality standards; however, bacterial concentrations generally remained elevated for five days following a storm (Ackerman and Weisberg, 2003). Data from 20 Southern California sites over a five-year span demonstrates all storms larger than 6 mm increased the ocean bacterial concentration in the county and only storms with less than 2.5 mm rainfall had no observable rainfall effect on the fecal coliform concentration of the beaches. Another study observing the effects rainfall has on runoff events and tributaries determined that the bacteriological parameters (colony, *Escherichia coli*, coliform, fecal streptococcal, and *Clostridium perfringens* counts) investigated increased considerably during extreme runoff events (Kistemann et al., 2002). The research asserts that regular samples (samples taken during periods of low or no rainfall) are inadequate for representing the microbial contamination of watercourse systems and water surveillance procedures must include extreme runoff circumstances to generalize the actual quality of the water way. Conversely, a recent study on the Chattahoochee River and Utoy Creek during the particularly rainy summer of 2013 did not find significant correlations between rainfall and *E. coli*, although the highest accumulated precipitation day of the season occurred during the sampling months; yet, the researcher found a positive correlation between MS2 and turbidity, rainfall the day of sampling and rainfall the day before sampling (Perkins 2013).

There is conflicting research on the importance of rainfall to the quality of watersheds but this may be attributable to the various sources of pollution. If the main contributor of water contamination is from point source effluent dumping directly into a water body, then the amount of rainfall will be unrelated to the concentration of pollutants. Research conducted during a dry season in Argentina found that since the river flow was continuously lower than 10 m^3 water quality during the dry season (May to November) had the worst water quality (Pesce and Wunderlin, 2000; Dasso, 1998). The researchers found that urban non-point pollution created a rise in TIN (total inorganic nitrogen concentration), while the city sewage discharge diluted the nitrate nitrogen but in turn raised the ammonia nitrogen, leading to DO consumption downstream. From the previous research indicating that wet seasons correlate with poorer water quality, the Pesce and Perkins studies are seemingly remarkable, but the characteristics of the areas being studied are key to determining the trends for that region; not all research is generalizable.

This information supports the seminal research that points to nonpoint pollution and urban surface runoff as being a main contributor to the decline in urban water bodies (Boehm et al., 2002; Lipp et al., 2001). Therefore, routine monitoring of the waterways in question is critical to determining what factors are influencing water quality degradation. Certain indices are key indicators of certain types of pollution. *E. coli* typically denotes the presence of fecal contamination, turbidity indicates the amount of suspended solids in a liquid, and high conductivity points to certain quantities of heavy metals. The parameters measured can detect key contaminants (Mosneag, et al. 2014).

2.3 Fecal Indicators

Since testing for all disease-causing bacteria in water is costly, water quality researchers have identified primary indicator bacteria that denote when fecal bacteria is present. According to recent research, *Escherichia coli* (*E. coli*) and Enterococci are most reliable for predicting disease-causing bacteria presence (Gregory and Frick, 2000). The US EPA recommends using *E. coli* and Enterococci for consistent monitoring programs due to their ability to show that fecal contamination has occurred. Initially, the Department of the Interior recommended that fecal coliform bacteria replace total coliform bacteria as the indicator of ambient water quality but subsequently, research conducted by the US EPA showed the relationship between swimming-associated gastroenteritis and indicator bacteria density at beaches. Thus recommending *Escherichia coli* bacteria as the preferred indicator bacteria for identifying fecal contamination in ambient freshwater (US Department of the Interior & US Geological Survey, 2012, Department of the Interior, 1968, U.S. Environmental Protection Agency, 1986).

Another indicator of water pollution is turbidity and although turbidity does not have a health-based guideline, the World Health Organization (2006) recommends that it should be below 0.1 NTU for adequate disinfection (Mosneag, et al. 2014). Since turbidity is thought to carry certain nutrients that produce biological activity and provides surface area to transport microorganisms throughout water systems, its ability to degrade a waterway has been explored by several studies. A study by McCoy and Olson found that turbidity counts were higher in surface water samples in the spring months and attributed this variability to heavy rain influence and the melting of snow packs on surface waters (McCoy and Olson, 1985). Another study by Bengraine and Marhaba (2003) also examined the relationship turbidity has on spatiotemporal variations of water quality and found similar results concerning turbidity counts. The researchers found that organoleptic parameters (turbidity, UV254, and color) increased about 12% in the spring and, parallel to the McCoy and Olson study, asserted that the variation is linked to the land washing process due to snow melt and heavy rain. These studies offer a differing snapshot of spring weather patterns when compared to the type of climate during the 2014 water-sampling period for this study. Rainfall was measured by the occurrence of a rain event the day of or day before a sampling round; however, there was no observed rain occurrence during the five-month period of Chattahoochee River sampling. This study will contribute to the water quality canon by identifying the variations that occur during a non-rainy season.

Another barometer of the ecological health of a body of water is dissolved oxygen (DO) since it is a critical parameter for fish protection, as fish cannot survive a DO content of <3 mg/L (Novotny, 2002). The temperature of a waterway is controlled directly by the ambient air temperature and indirectly influenced by vegetation; DO is controlled by these factors (Chang, 2005). Sanchez et al. accounted for vegetation influences in the measuring of oxygen deficit variation, the average photosynthesis rate and the average respiration rate (Sanchez et al., 2007). The authors found that DO and dissolved oxygen deficit (difference between the amount of dissolved oxygen in water and the saturation concentration at the temperature of the water mass sampled) can be utilized to predict the water quality index of watersheds. An article by Cox states that the variability of DO in rivers is caused by many factors, one of which being the introduction of dissolved oxygen from other sources, such as tributaries (Cox, 2003). Since the Chattahoochee River has several tributaries along the sampling route, according to Cox, a high amount of DO would be probable. However, DO depletion can also arise due to the oxidation of organic material, which is also referred to as the biochemical oxygen demand (BOD). Cox's study found that BOD is added to water bodies through local runoff, which also occurs at a high rate on the Chattahoochee, possibly resulting in lower DO outcomes. Since the river in question has many elements examined in various, but differing, research, this study will offer a multivariate investigation of a unique body of water.

A coliphage, a bacteriovirus that attacks coliform, is typically present wherever coliform bacteria exists, which makes it a potential indicator of fecal contamination. Recent studies have focused on bacterioviruses serving as indicators of pollution, but not many have addressed the part MS2 may play in fecal contamination identification (Rosario et al., 2009; Mehle, et al., 2014; Fong and Lipp, 2005). In a pollution remediation study, researchers found that bacteriophages (investigated bacteriophage 0X174, bacteriophage MS2, and bacteriophage B40-8) were more resistant than fecal coliforms and enterococci. Though, F-specific RNA bacteriophages were not as opposed to removal and inactivation of fecal coliform bacteria processes in the summer, due to changes in water temperature, pH, and sunlight irradiation (Duran, et al., 2002). While the previously mentioned studies speak on the importance human-based viruses have on assessing waterborne enteric disease, the study by Fong and Lipp (2005) suggest including other host-specific viruses in the investigation of water quality. Stating that a multispecies viral analysis would aid in determining the sources of pollution that effect humans and animals.

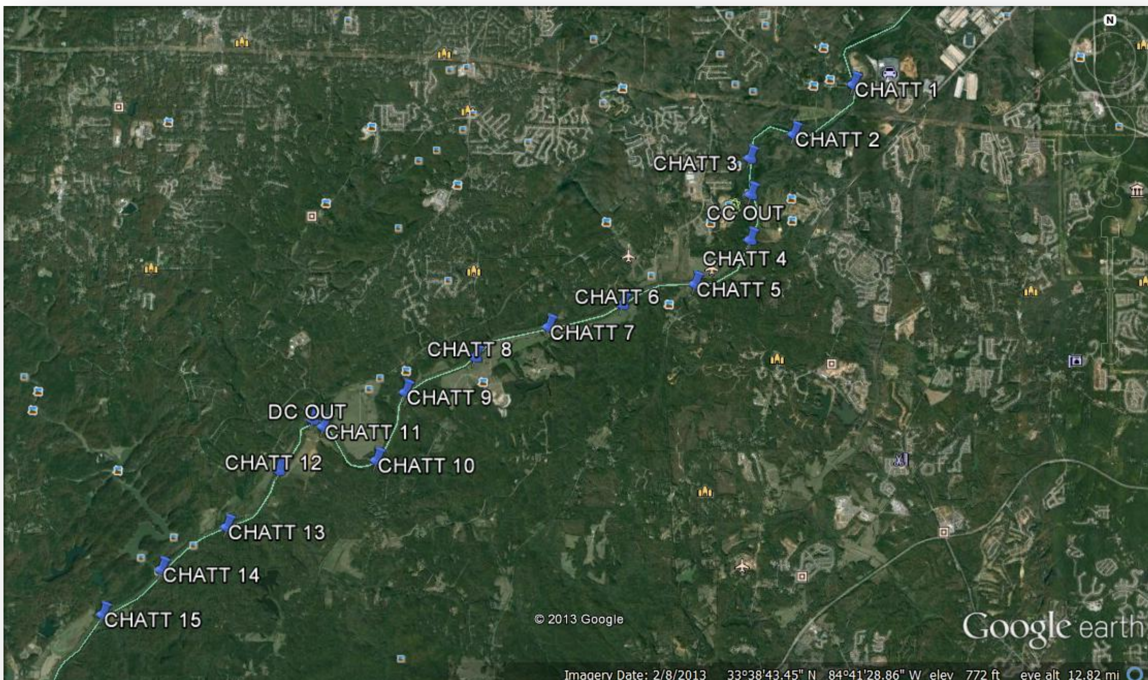
CHAPTER III

METHODS

3.1 River and Creek Sample Site Description

Fifteen locations were designated as water sample collection sites along fourteen-miles of the Chattahoochee River with each collection site approximately one mile apart.

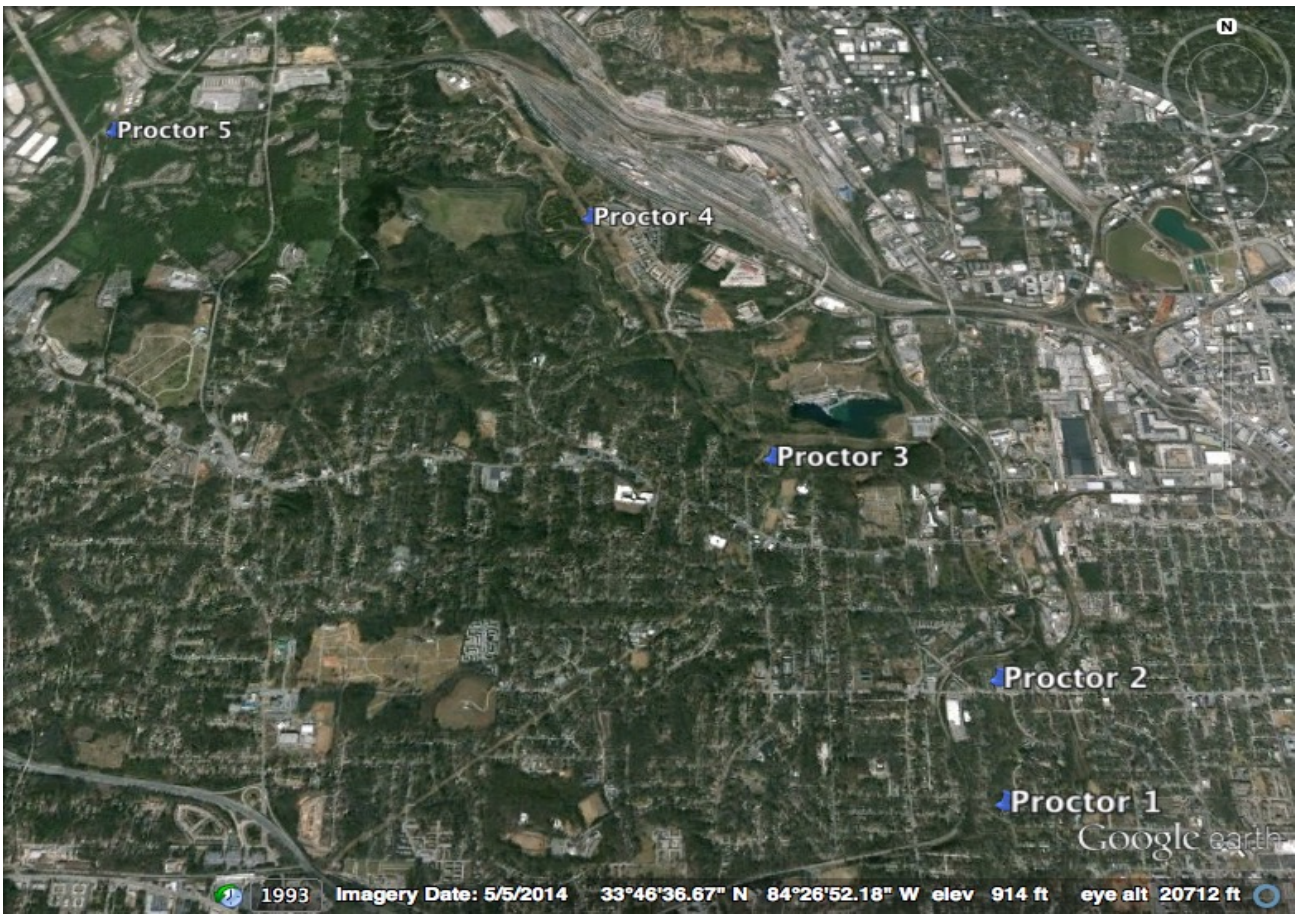
Map 1: Chattahoochee River Sample Sites



Both the Camp Creek and Douglas County wastewater treatment plants have effluent outfalls along the fourteen-mile stretch in which the sample collection sites were located. The Camp Creek Outfall is positioned between sites three and four and the Douglas County Outfall is between sites eleven and twelve.

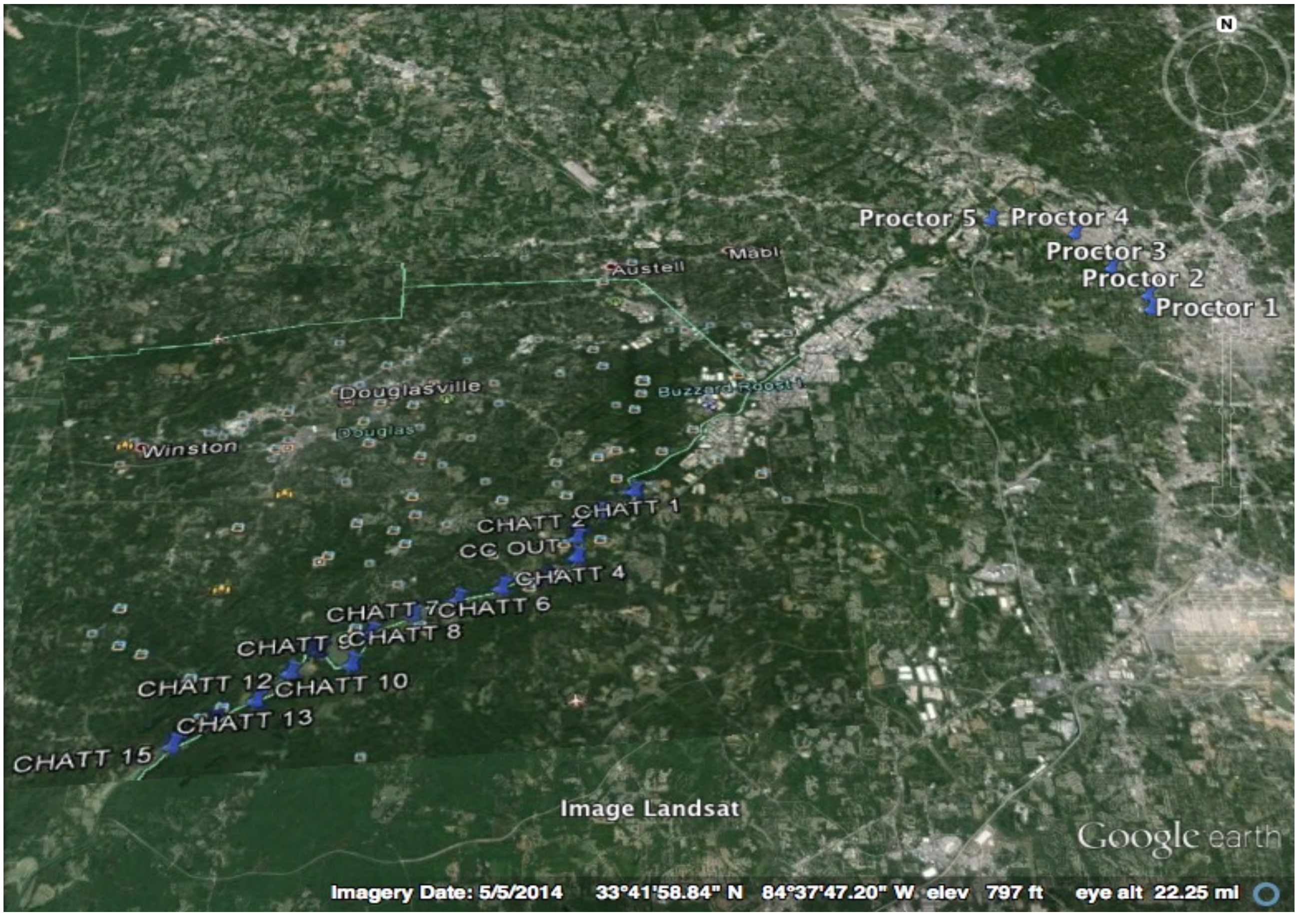
Proctor Creek, a sixteen square mile watershed located in primarily residential and highly urbanized areas, flows directly into the Chattahoochee River Basin. The creek was sampled at five sites along a five-mile long stretch. The first sampling site (Burbank) is located the furthest downstream and each of the following sites flow upstream, with sampling site five (Northwest) being the closest to the Chattahoochee River.

Map 2: Proctor Creek Sample Site



The approximate distance from the last sample site of Proctor Creek to the first sample site of the Chattahoochee River is 11.91 miles.

Map 3: Chattahoochee River and Proctor Creek Sample Sites



3.2 Sample Collection

3.2.1 Chattahoochee River

The Chattahoochee River was sampled on 5/12/14, 6/19/14, 7/10/14, 8/5/2014, and 9/11/14 by boat. Using the grab sample method, one liter of river water was collected in sterilized bottles at each of the water sample sites and at the two water treatment outfall sites. Effluent was collected directly from the outfall pipeline at the Camp Creek Outfall if the wastewater plant was releasing effluent at the time of sample collection. Douglas County Outfall samples were not collected directly from the pipeline but within close proximity if the outfall was unreachable by boat. In addition to water samples, the date, time, geographic location (latitude and longitude), dissolved oxygen (DO), and pH were recorded at each sample site on each sampling round. All liter bottles containing samples were stored in coolers filled with ice to preserve the samples while being transported from the Chattahoochee River to the Georgia State University (GSU) School of Public Health (SPH) lab. Samples remained in coolers on ice until processed, which was no longer than six hours. Turbidity was measured in the SPH laboratory using a Hach Turbidimeter (Hach, Loveland, CO).

3.2.2 Proctor Creek

Chattahoochee Riverkeeper Neighborhood Water Watchers sampled Proctor Creek on 5/8/14, 5/15/14, 6/17/14, 6/19/14, 6/24/14, 7/7/14, 7/10/14, 7/17/14, 8/7/14, 8/14/14, and 9/11/14. Using the grab sample method, water was collected in sterile Whirl Pack bags at each site and stored on ice until delivered at the CRK laboratory. The Chattahoochee Riverkeeper recorded *E. coli* concentrations (MPN/100mL) using the Quanti-Tray IDEXX method, turbidity, rainfall, fluorometry, and conductivity. All data was collected by CRK and shared for this research project.

3.3 Detection of *Escherichia coli* by Membrane Filtration

Materials:

Sidearm flasks, magnetic filter funnels, 0.45-micron filters, 100% ethanol, forceps, bunson burner, 50 mL and 1 mL pipettes, 60x15mm plates containing BioRad Rapid *E. coli* 2 agar (thawed and not older than 2 weeks) (Bio-Rad, Marnes, La Coquette, France), and an incubator set to 35^{o} C.

Methods:

Negative controls were processed prior to filtration of each sample. Forceps were placed into 100% ethanol and sterilized in a flame before placing the filter film on a magnetic filter funnel. Each liter bottle from the 15 sample sites and 2 outfall sites were retrieved from the cooler and sample water was poured over the filtration filter using a sterilized pipette. Dilutions at 50 mL and 10 mL of the sample water were completed for all samples. The first two sample rounds (5/12/14 and 6/19/14) also had dilutions at 1 mL. Before placing the filter on the plate, the funnel was rinsed with deionized (DI) water. The steps above were repeated for all samples, where each sample site had its own filter funnel, negative control, two dilutions at 10 mL and two dilutions at 50 mL (the second and fifth sample round had one dilution at each volume). After each dilution, each filter was rinsed with DI water to ensure entire sample was filtered. Once the samples were filtered, the plates were put in an incubator at 35^{o} C for 18-24 hours. After incubation, the plates were placed on a light box to count *E. coli* colonies. Colony counts were expressed as CFU/100mL.

3.4 Detection of MS2 by Spot Plate Enrichment Assay

Water Samples were processed according to the EPA's Method 1601: Male-specific (f+) and Somatic Coliphage in Water Two-step Enrichment Procedure (EPA, 2001). Samples were scored for presence/absence of MS2.

3.5 Data Sources

Riverflow data was obtained from the USGS website (USGS site 02336490 Chattahoochee River at GA 280) (USGS, 2014).

Dissolved Oxygen was determined at each Chattahoochee River sample site by a trained staff member of the CRK. Turbidity was determined in the GSU SPH lab while the samples were processed using a Hach turbidimeter.

3.6 Statistical Analyses

All original data was organized and stored in Microsoft Excel 2008. Prior to statistical analyses, Microsoft Excel 2010 was also used to convert all *E. coli* data into CFU/100ml and a logarithmic transformation was used to ensure normality of the data. Graphs were created using GraphPad Prism version 5. Statistical Analyses of the data was performed with GraphPad Prism as well. For all statistical analyses, the level of significance was reported as $p < .05$.

CHAPTER IV

RESULTS

4.1 Chattahoochee River

Table 1: Univariate analysis of selected water quality variables sampled from the Chattahoochee River by site, Atlanta, Georiga 2014.

E. coli **by site***

	Range	Minimum	Maximum	Mean
Site 1	0.34	1.63	1.97	1.83
Site 2	0.50	1.48	1.97	1.76
Site 3	0.59	1.44	2.03	1.87
Camp Creek Outfall	1.79	0.00	1.79	0.57
Site 4	0.50	1.61	2.11	1.86
Site 5	0.55	1.55	2.11	1.93
Site 6	0.65	1.56	2.22	1.87
Site 7	0.57	1.57	2.14	1.87
Site 8	0.41	1.65	2.05	1.86
Site 9	0.62	1.57	2.19	1.90
Site 10	0.69	1.43	2.11	1.87
Site 11	0.72	1.46	2.19	1.88
Douglas County Outfall	1.51	0.30	1.81	1.21
Site 12	0.71	1.30	2.01	1.63
Site 13	0.72	1.20	1.92	1.71
Site 14	0.49	1.28	1.77	1.57
Site 15	0.38	1.32	1.70	1.61

Turbidity by site**

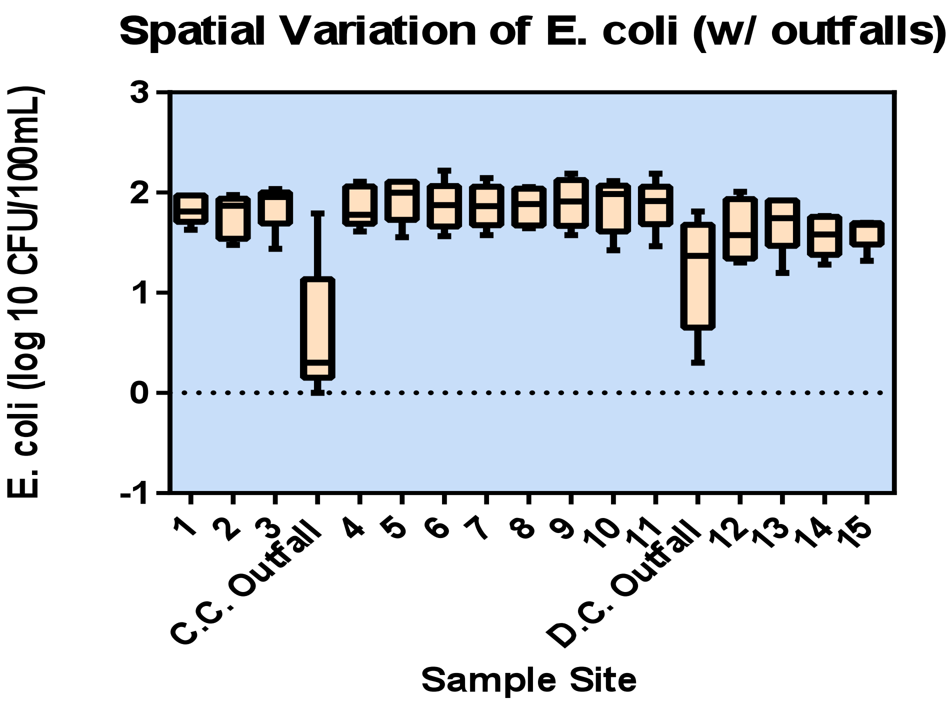
	Range	Minimum	Maximum	Mean
Site 1	7.04	1.81	8.85	5.31
Site 2	5.80	1.95	7.75	3.49
Site 3	6.03	1.80	7.83	3.88
Camp Creek Outfall	7.55	0.23	7.78	3.51
Site 4	6.05	1.94	7.99	5.14
Site 5	5.69	2.41	8.10	5.35
Site 6	8.56	2.04	10.60	5.15
Site 7	7.43	1.97	9.40	4.88
Site 8	5.26	1.99	7.25	4.52
Site 9	6.43	1.96	8.39	3.82
Site 10	7.17	2.57	9.74	5.65
Site 11	4.11	1.96	6.07	3.92
Douglas County Outfall	3.42	2.57	5.99	4.45
Site 12	4.03	2.12	6.15	3.98
Site 13	7.96	0.00	7.96	3.00
Site 14	7.36	0.00	7.36	3.31
Site 15	8.38	0.00	8.38	3.14

Dissolved Oxygen by Site***

	Range	Minimum	Maximum	Mean
Site 1	1.14	7.46	8.60	7.88
Site 2	1.11	7.49	8.60	7.76
Site 3	0.51	7.49	8.00	7.70
Camp Creek Outfall	0.26	7.72	7.98	7.83
Site 4	0.90	7.30	8.20	7.71
Site 5	0.99	7.21	8.20	7.64
Site 6	0.95	7.25	8.20	7.67
Site 7	0.90	7.20	8.10	7.69
Site 8	0.97	7.13	8.10	7.61
Site 9	1.10	7.10	8.20	7.61
Site 10	0.61	7.09	7.70	7.41
Site 11	0.83	6.97	7.80	7.34
Douglas County Outfall	0.47	7.23	7.70	7.47
Site 12	1.50	6.50	8.00	7.25
Site 13	0.55	6.88	7.43	7.17
Site 14	0.84	6.86	7.70	7.31
Site 15	1.07	6.83	7.90	7.36

* All *E.coli* concentrations are presented as log 10 CFU/100mL
** Turbidity values are presented as NTU
*** Dissolved Oxygen values are presented as mg/L

Figure 1: Spatial Variation of *E. coli* among Chattahoochee Water Samples



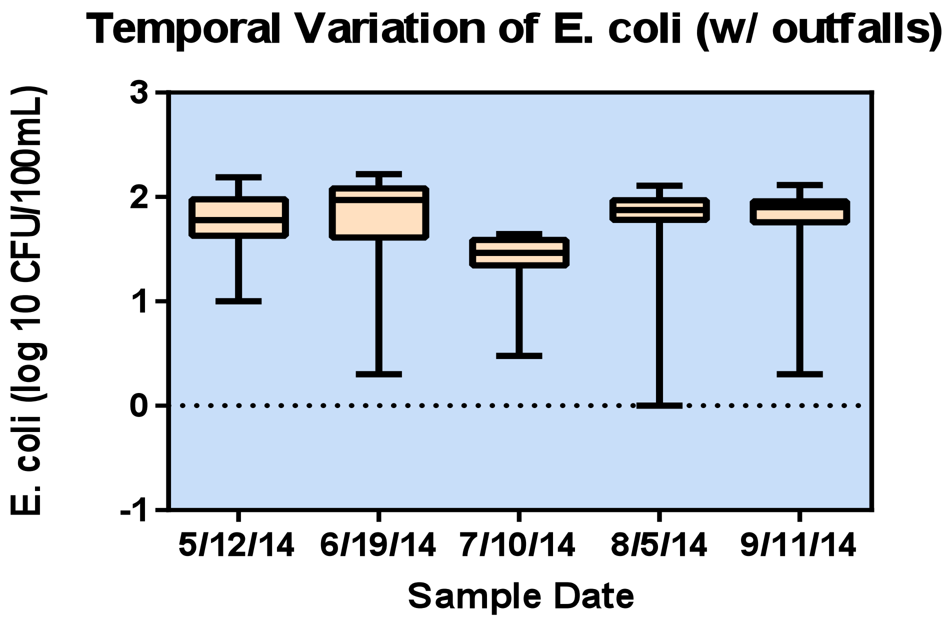
As show in Table 1 and Figure 1, the mean *E. coli* concentrations across sites for all sampling dates were similar, mean *E. coli* levels were approximately 2 log_{10} CFU/100 mL across sites (p=2.53). There is a slight decrease in the *E. coli* concentrations at the outfall sites (approximately 1.25 log_{10} CFU/100). There was a statistically significant difference in the mean *E. coli* concentrations between sample sites with the highest and lowest mean values (p=0.0291 between sites 14 and 5; Table 3a).

Table 3a: Determination of statistical significance between samples with the highest and lowest mean values of *E. coli* among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean concentrations of *E. coli***				
Between site 14 (lowest) and site 5 (highest)	1.57	1.93	-0.6783 to -0.04751	0.0291
Between sample dates 7/10/14 (lowest) and 6/19/14 (highest)	1.42	1.82	-0.5279 to -0.1054	0.0058
Spatial ANOVA				0.253
Temporal ANOVA				<0.0001

* t-test with level of significance reported as p<.05
** *E. coli* concentrations in 10 log CFU/100mL

Figure 2: Temporal variation of *E. coli* among Chattahoochee Water Samples



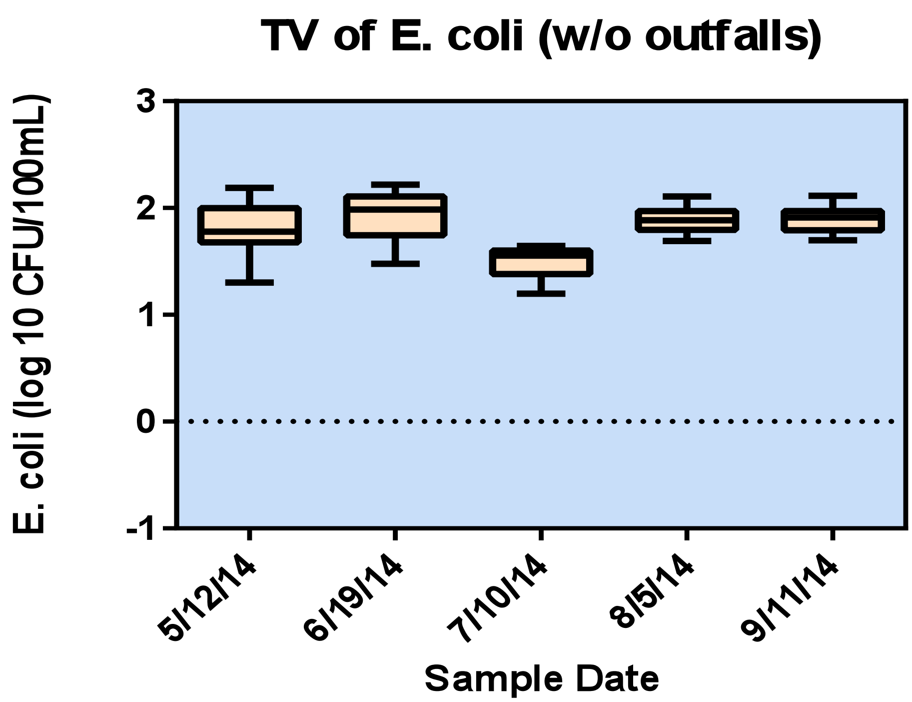


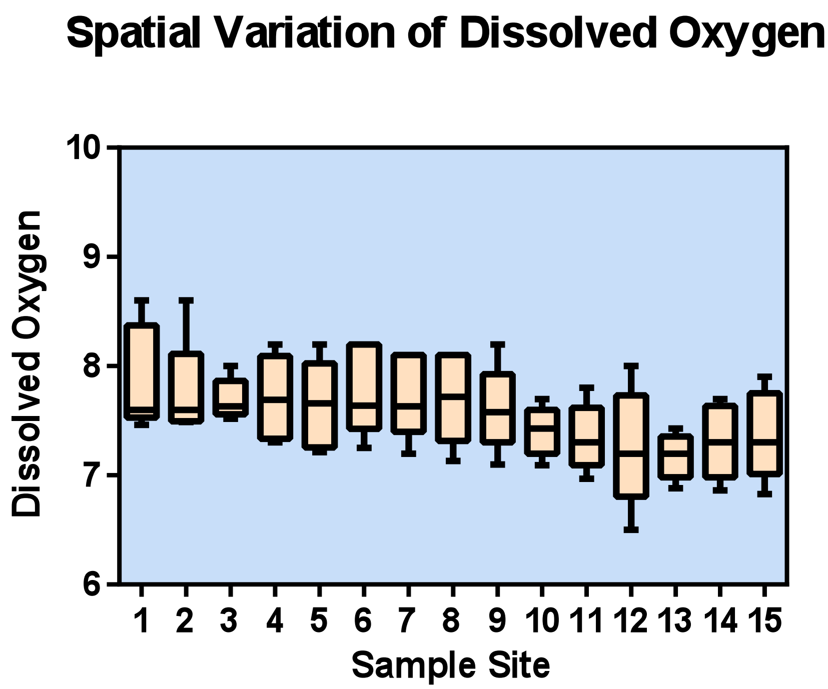
Table 2: Univariate analysis of selected water quality variables sampled from the Chattahoochee River by date, Atlanta, Georgia, 2014.

E. coli **by date***	Range	Minimum	Maximum	Mean
5/12/14	1.19	1.00	2.19	1.73
6/19/14	1.92	0.30	2.22	1.82
7/10/14	1.17	0.48	1.65	1.42
8/5/14	2.11	0.00	2.11	1.77
9/11/14	1.81	0.30	2.11	1.79
Turbidity by date**				
5/12/14	4.20	4.29	8.49	7.29
6/19/14	10.60	0.00	10.60	5.45
7/10/14	4.20	1.11	5.31	2.90
8/5/14	5.74	0.23	5.97	2.19
9/11/14	5.89	1.03	6.92	3.50
Dissolved Oxygen by date***				
5/12/14	8.60	0.00	8.60	7.09
6/19/14	0.77	7.43	8.20	7.72
7/10/14	1.06	7.08	8.14	7.49
8/5/14	7.80	0.00	7.80	7.01
9/11/14	7.60	0.00	7.60	6.29

* All E. coli concentrations are presented as log 10 CFU/100mL
** DO values are presented as mg/L
*** Turbidity values are presented as NTU

As shown in Table 2 and Figure 2, there is a variation found among *E. coli* concentrations across sample dates for all sample sites. A one-way ANOVA found the Temporal Variation of *E. coli* counts across all sampling dates to be statistically significant ($p<0.0001$), with the lowest mean *E. coli* concentration found on 7/10/14 (1.42 $\log_{10}$ CFU/100mL) and the highest mean *E. coli* concentration found on 6/19/14 (1.82 $\log_{10}$ CFU/100mL). Paired samples t-test determined that the differences in mean *E. coli* concentrations between these two sample dates were statistically significant ($p = 0.0058$; Table 3a).

Figure 3: Spatial Variation of Dissolved Oxygen among Chattahoochee Water Samples



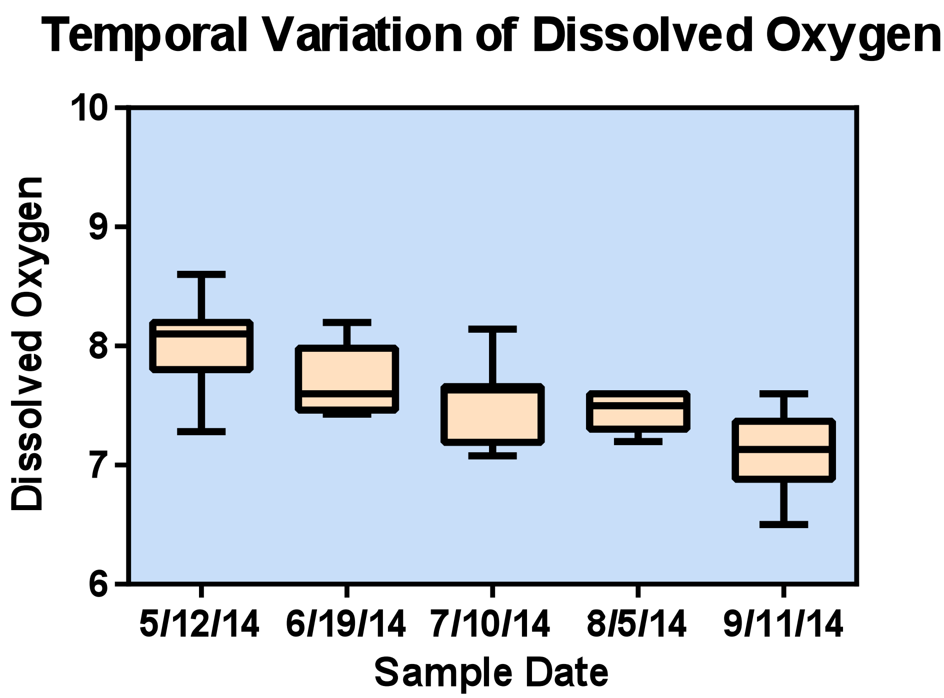
As shown in Table 1 and Figure 3, there is a variation found among DO values across sites for all sampling dates ($p<0.0001$). There was also a statistically significant difference in mean DO values between sample site 13 and site 1 ($p=0.0165$; Table 3b).

Table 3b: Determination of statistical significance between samples with the highest and lowest mean values of DO among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean values for DO**				
Between site 13 (lowest) and site 1 (highest)	7.17	7.88	-1.245 to -0.1672	0.0165
Between sample dates 9/11/14 (lowest) and 6/19/14 (highest)	6.29	7.72	-0.7531 to -0.3869	<0.0001
Spatial ANOVA				0.0775
Temporal ANOVA				<0.0001

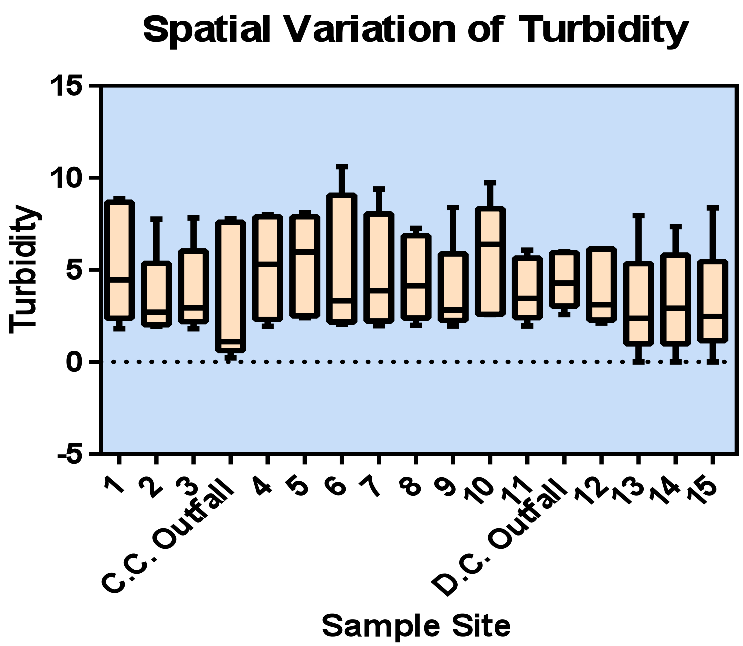
* t-test with level of significance reported as p<.05
** DO values in mg/L

Figure 4: Temporal Variation of Dissolved Oxygen among Chattahoochee Water Samples



As shown in Table 2 and Figure 4, there is a variation found among DO values across sample dates for all sample sites. A one-way ANOVA found the temporal variation of dissolved oxygen across all sampling dates to be statistically significant ($p<0.0001$), with the lowest mean DO values found on 9/11/19 (6.29 mg/L) and the highest mean DO value found on 6/19/14 (7.72 mg/L). Paired samples t-test determined that the differences in mean DO values between these two sample dates were statistically significant ($p<0.0001$, Table 3b).

Figure 5: Spatial Variation of Turbidity among Chattahoochee Water Samples



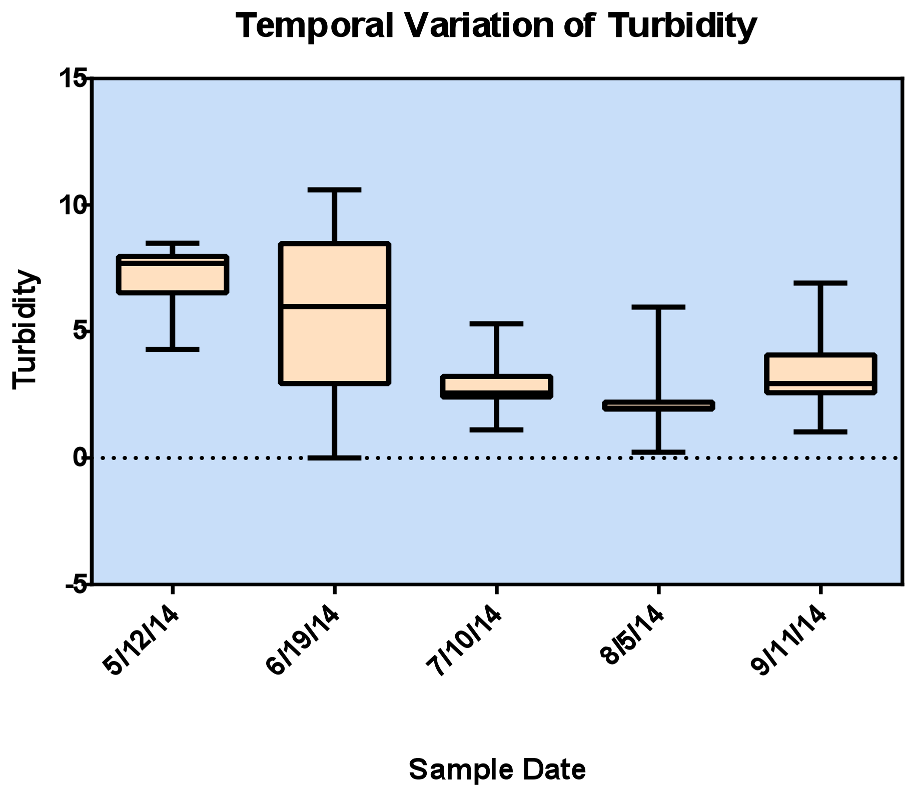
As shown in Table 1 and Figure 5, the mean turbidity values across sites for all sampling dates were similar. Further analysis showed that there were no statistical significant differences in mean turbidity values between sample sites with the highest and lowest mean turbidity values (p=0.2031; Table 3c).

Table 3c: Determination of statistical significance between samples with the highest and lowest mean values of turbidity among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean values for Turbidity**				
Between site 13 (lowest) and site 10 (highest)	3	5.65	-7.042 to 1.754	0.2031
Between sample dates 8/5/14 (lowest) and 5/12/14 (highest)	2.19	7.29	-5.930 to -4.276	<0.0001
Spatial AVONA				0.9147
Temporal ANOVA				<0.0001

* t-test with level of significance reported as p<.05
** Turbidity values in NTU

Figure 6: Temporal Variation of Turbidity among Chattahoochee Water Samples



As shown in Table 2 and Figure 6, there is a variation found among turbidity values across sample dates for all sample sites, with the lowest mean turbidity value found 8/5/14 (2.19 NTU) and the highest mean turbidity value found on 5/12/14 (7.29 NTU). Paired sample t-tests determined that the differences in mean turbidity values between these two sample dates were statistically significant ($p<0.0001$; Table 3c). A one-way ANOVA determined that the differences between the mean turbidity values between all sample dates were statistically significant ($p<0.0001$).

Table 4a: Analysis of Pearson's correlations between *E. coli* and Dissolved Oxygen sampled from the Chattahoochee River, Atlanta, Georgia, 2013.

E.coli and DO	P-Value*
Site 1	0.33
Site 2	0.11
Site 3	0.74
Site 4	1.00
Site 5	0.93
Site 6	0.71
Site 7	0.98
Site 8	0.12
Site 9	0.48
Site 10	0.97
Site 11	0.29
Site 12	0.12
Site 13	0.98
Site 14	0.80
Site 15	0.79

*Pearson's correlation coefficient with level of significance reported as $p < .05$

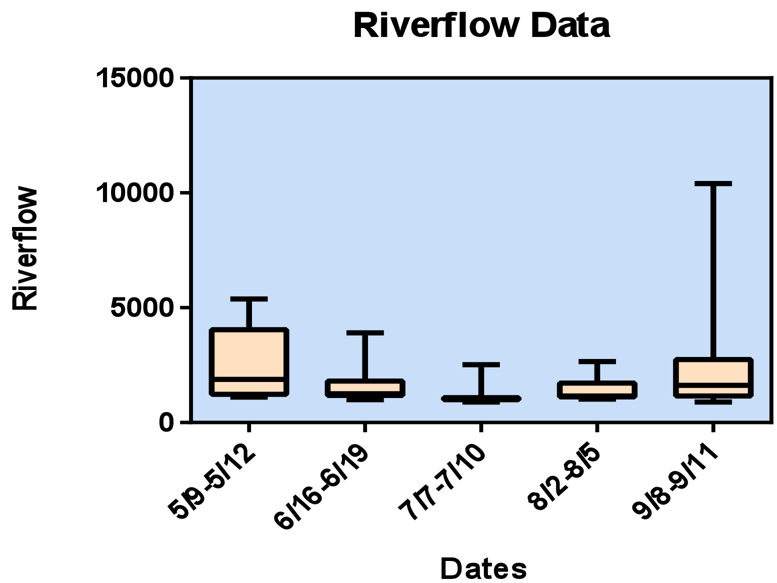
As shown in Table 4a, *E. coli* concentrations from the Chattahoochee water samples were not significantly correlated with dissolved oxygen at any of the sampling sites. Noticeably, DO increases at site 4 and site 13, which are both downstream from outfalls.

Table 4b: Analysis of Pearson's correlation between E. coli and Turbidity sampled from the Chattahoochee River, Atlanta, Georgia, 2014.

E. coli and Turbidity	Pearson's R	P-Value*
Site 1	0.12	0.85
Site 2	-0.72	0.17
Site 3	-0.11	0.86
Site 4	0.05	0.93
Site 5	0.78	0.12
Site 6	0.67	0.22
Site 7	0.68	0.25
Site 8	0.11	0.86
Site 9	0.76	0.14
Site 10	0.74	0.15
Site 11	0.61	0.27
Site 12	-0.50	0.39
Site 13	-0.05	0.94
Site 14	0.17	0.78
Site 15	0.16	0.80

* Pearson's correlation coefficient with level of significance reported as $p < .05$

Figure 7: Analysis of Riverflow sampled from the Chattahoochee River, Atlanta, Georgia, 2014.



Riverflow was recorded three days before water samples were collected from the Chattahoochee. As shown in Table 4c and Figure 7, there is a temporal variation in the riverflow of the Chattahoochee River. A one-way ANOVA found the temporal variation of riverflow across all sampling dates to be statistically significant ($p<0.0001$), with the highest mean riverflow found between 5/9/14 and 5/12/14 and the lowest mean riverflow found between 7/7/14 and 7/10/14. Paired samples t-test determined that the differences in mean riverflow between these two sample dates were statistically significant ($p<0.0001$, Table 4c). The dates with the lowest mean riverflow (7/7/14-7/10/14) occurred before the lowest *mean E. coli* concentration was collected on 7/10/14.

Table 4c: Determination of statistical significance between riverflow samples among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean	P-Value*
	Lowest	Highest		
Mean Riverflow**				
Between sample dates 7/7-7/10 (lowest) and 5/9-5/12 (highest)	1161.922	2577.03	-1573 to -1257	<0.0001
Temporal ANOVA				<0.0001

* t-test with level of significance reported as p<.05

** Riverflow values in ft^3/min

Figure 8: MS2 Presence among all samples sampled from the Chattahoochee River

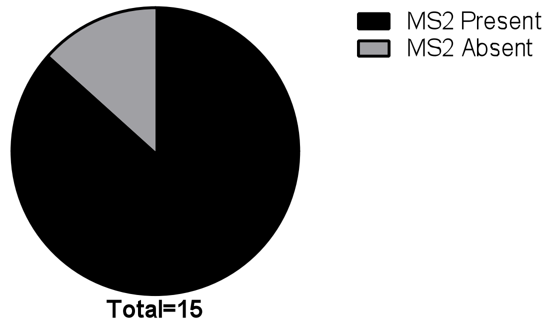


Table 4d: Analysis of t-test correlations between *E. coli* and MS2 sampled from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean values for *E. coli* and MS2				
Absent MS2 between sample dates 7/10/14 (lowest) and 6/19/14 (highest)	1.33	1.81	0.004177 to 0.9478	0.0482
Present MS2 between sample dates 7/10/14 (lowest) and 6/19/14 (highest)	1.48	1.81	0.1033 to 0.7013	0.0129

* Pearson's correlation coefficient with level of significance reported as $p<.05$

Figure 8 and Table 5 indicate that across all sampling dates, most water samples had MS2 present. Table 5 shows the mean concentrations of *E. coli* were similar for sites across all sample dates, regardless of the presence or absence of MS2, an ANOVA determined no statistically significant difference (p=0.2691). As shown in Table 4d, there is a statistically significant difference in mean *E. coli* concentrations in the presence or absence of MS2 of all sample sites between the date with the lowest *E. coli* concentration (7/10/14) and the date with the highest (6/19/14).

Table 5: Mean E. coli concentrations based on the presence or absence of MS2 among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		
	MS2 Present	MS2 Absent	MS2 Ratio
Mean E.coli and MS2			
Site 1	1.80	1.97	4/5
Site 2	1.83	1.67	3/5
Site 3	1.83	2.03	4/5
Camp Creek Outfall	0.15	0.86	2/5
Site 4	1.79	2.11	4/5
Site 5	2.03	1.55	4/5
Site 6	1.85	1.89	3/5
Site 7	1.87	1.86	3/5
Site 8	1.86	1.86	3/5
Site 9	1.90	0.00	5/5
Site 10	1.84	1.99	4/5
Site 11	1.91	1.70	3/5
Douglas County Outfall	1.68	1.38	2/5
Site 12	1.64	1.58	4/5
Site 13	1.65	1.75	4/5
Site 14	1.57	0.00	5/5
Site 15	1.69	1.65	3/4
Mean *E.coli* and MS2 concentrations by date			
5/12/14	1.81	1.49	13/15
6/19/14	1.88	1.81	3/15
7/10/14	1.48	1.33	10/14
8/5/14	1.77	0.00	15/15
9/11/14	1.79	0.00	15/15

Table 6: Determination of spatial variation of mean *E. coli* concentrations upstream and downstream the Camp Creek Outfall and Douglas County Outfall among water samples from the Chattahoochee River, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence interval of the Mean Difference	P-value*
	Upstream	Downstream		
Mean Concentrations of *E. coli* at Camp Creek Outfall**				
Upstream/Downstream by 1 site	1.87	1.86	-0.3382 to 0.3117	0.93
Upstream/Downstream by 2 sites	1.82	1.89	-0.1238 to 0.2802	0.43
Upstream/Downstream by 3 sites	1.82	1.89	-0.08892 to 0.2139	0.41
Mean Concentrations of *E. coli* at Douglas County Outfall***				
Upstream/Downstream by 1 site	1.88	1.63	-0.6673 to 0.1589	0.19
Upstream/Downstream by 2 sites	1.87	1.67	-0.4.617 to 0.04474	0.10
Upstream/Downstream by 3 sites	1.88	1.63	-0.4348 to 0.06220	0.01

* t-test with level of significance reported as $p < .05$
** Comparison of sites 3 and 4; sites 2/3 and 4/5; and sites 1/2/3 and 4/5/6
*** Comparison of sites 11 and 12; 10/11 and 12/13; and sites 9/10/11 and 12/13/14

As shown in Table 6, mean concentrations of *E. coli* were similar for sites upstream and downstream from the Camp Creek Outfall. However, differences in the mean *E. coli* levels were found between the upstream and downstream sample sites of the Douglas County Outfall. Sites 9, 10, and 11 were compared to sites 12, 13, and 14 and statistically significant differences in the mean *E. coli* concentrations were found ($p = 0.01$).

4.2 Proctor Creek

Table 7: Univariate analysis of selected water quality varibles from the Proctor Creek by site, Atlanta, Georgia, 2014.

E. coli* by site

	Range	Minimum	Maximum	Mean
Site 1	0.40	2.63	3.03	2.76
Site 2	1.43	3.47	4.91	4.11
Site 3	0.55	2.19	2.74	2.46
Site 4	1.55	2.00	3.55	2.55
Site 5	1.61	2.18	3.79	2.79

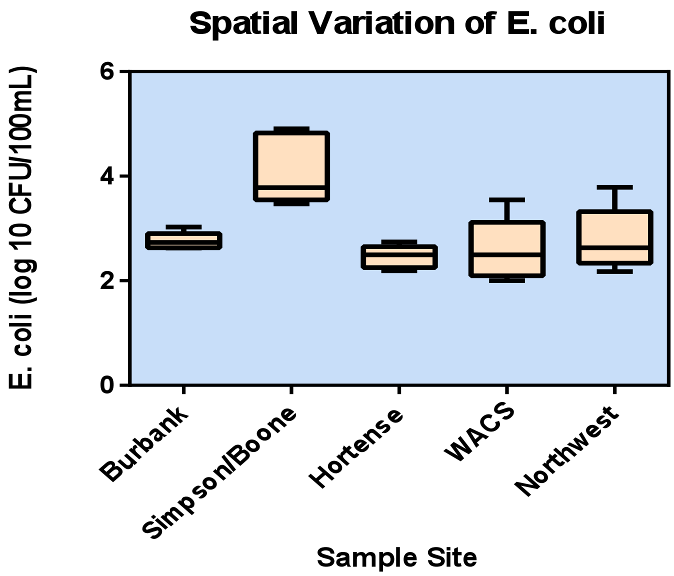
Turbidity by site**

	Range	Minimum	Maximum	Mean
Site 1	16.10	2.90	19.00	8.42
Site 2	36.45	1.75	38.20	10.23
Site 3	1.39	1.46	2.85	2.08
Site 4	11.48	2.12	13.60	5.33
Site 5	21.84	1.56	23.40	6.48

* All *E. coli* concentrations in water are presented as log 10 MPN/100mL

** Turbidity values are presented as NTU

Figure 9: Spatial Variation of *E. coli* among the Proctor Creek Water Samples



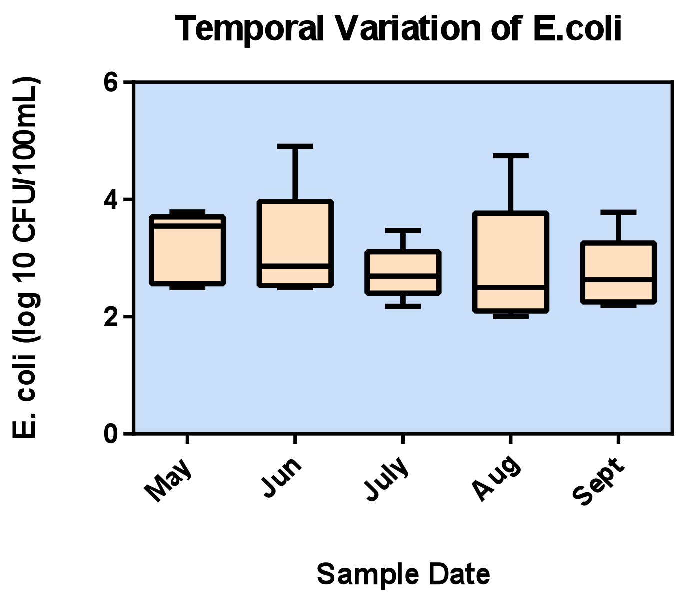
From Table 8 and Figure 9, there is a visible trend in the mean *E. coli* concentrations for each site, with a statistically significant difference between the lowest mean *E. coli* concentration at site 3 and the highest mean *E. coli* concentration found at site 1 (p= 0.0008). An ANOVA determined that the spatial variation of *E. coli* is significant as well (p= 0.0003).

Table 8: Determination of statistical significance between samples with the highest and lowest mean concentrations of *E. coli* among water samples from the Proctor Creek, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean concentrations of *E. coli* in water**				
Between site 3 (lowest) and site 2 (highest)	2.46	4.11	-2.370 to -0.9197	0.0008
Between sample dates September (lowest) and May (highest)	2.69	3.22	-1.387 to 0.4129	0.25
Spatial ANOVA				0.0003
Temporal ANOVA				0.3599

* t-test with level of significance reported as p<.05
** *E. coli* concentrations in 10 log MPN/100mL

Figure 10: Temporal Variation of *E. coli* among Proctor Creek Water Samples



As shown in Figure 10 and Table 9, there seems to be a temporal variation among the *E. coli* concentration in water across sample dates, with the highest mean *E. coli* concentration in June (7.57 log_{10} MPN/100mL) and the lowest in July (2.32 log_{10} MPN/100mL), but possibly due to the small sample size no statistically significant temporal variation was observed (p= 0.3599).

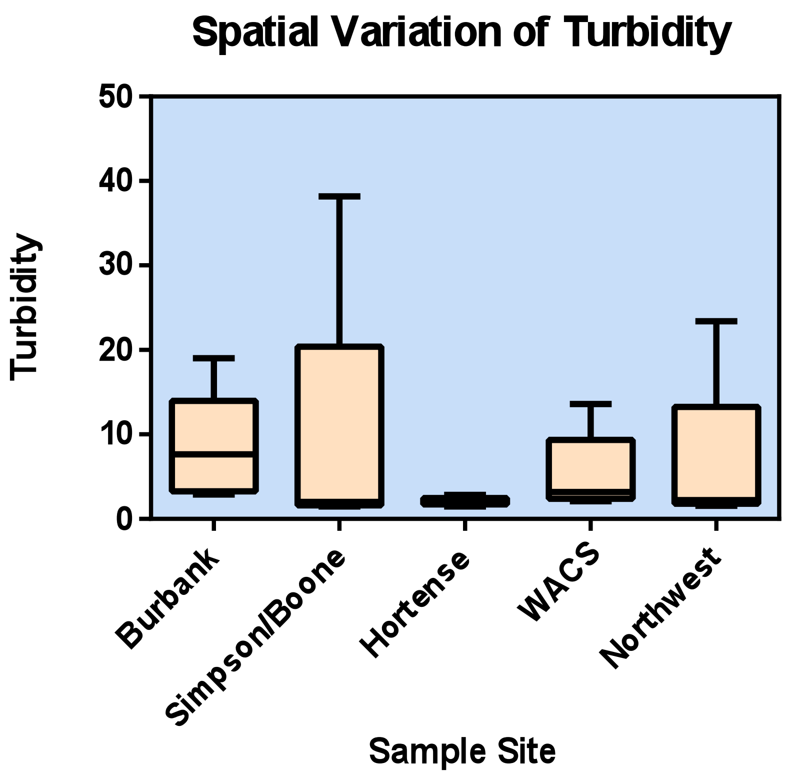
Table 9: Univariate analyses of selected water quality variables sampled from the Proctor Creek by date, Atlanta, Georgia, 2014.

	Range	Minimum	Maximum	Mean
E.coli in water by date*				
5/8/14	1.12	2.50	3.62	2.92
5/15/14	0.24	3.55	3.79	3.67
6/17/14	0.00	2.86	2.86	2.86
6/19/14	0.53	2.50	3.03	2.70
6/24/14	0.00	4.91	4.91	4.91
7/7/14	0.00	3.47	3.47	3.47
7/10/14	0.46	2.18	2.63	2.40
7/17/14	0.05	2.69	2.74	2.72
8/7/14	0.78	2.00	2.78	2.32
8/14/14	2.25	2.50	4.75	3.62
9/11/14	1.59	2.19	3.78	2.73
Turbidity by date**				
5/8/14	17.25	1.75	19.00	7.57
5/15/14	9.80	13.60	23.40	18.50
6/17/14	0.00	2.23	2.23	2.23
6/19/14	0.97	2.66	3.63	3.05
6/24/14	0.00	38.20	38.20	38.20
7/7/14	0.00	2.01	2.01	2.01
7/10/14	6.08	1.56	7.64	4.60
7/17/14	3.05	2.03	5.08	3.56
8/7/14	7.47	1.46	8.93	4.20
8/14/14	3.49	3.13	6.62	4.88
9/11/14	1.09	2.10	3.19	2.58

* *E. coli* concentrations are presented as log 10 MPN/100mL

**Turbidity values are presented as NTU

Figure 11: Spatial Variation of Turbidity among Proctor Creek Water Samples



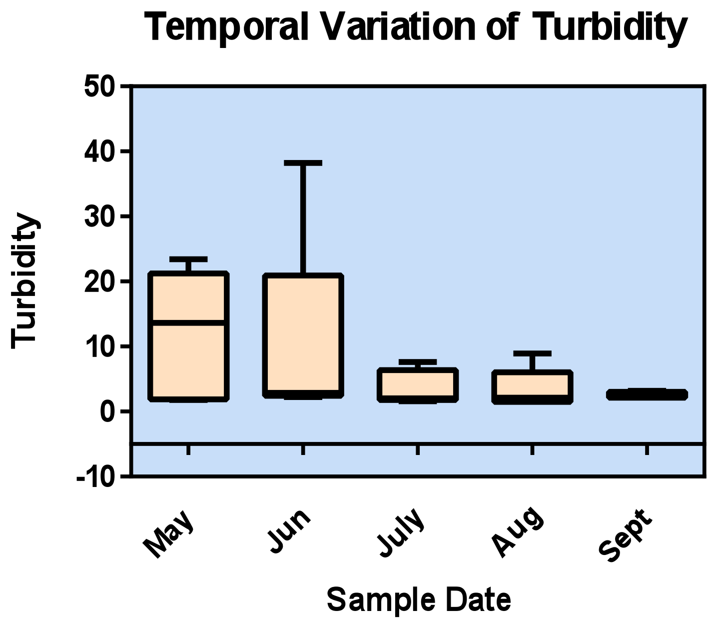
Based on Figure 11 and Table 10, the mean turbidity values across sites for all sampling dates were similar. Further analysis determined there were no statistically significant differences in mean turbidity values between sample sites (p= 0.45; Table 10).

Table 10: Determination of statistical significance between samples with the highest and lowest mean values of turbidity among water samples from the Proctor Creek, Atlanta, Georgia, 2014.

	Mean Values		95% Confidence Interval of the Mean Difference	P-Value*
	Lowest	Highest		
Mean concentrations of turbidity in water**				
Between site 3 (lowest) and site 2 (highest)	2.08	10.23	-24.41 to 8.107	0.289
Between sample dates September (lowest) and May (highest)	2.58	11.94	-27.19 to 14.69	0.4538
Spatial ANOVA				0.6682
Temporal ANOVA				0.3145

* t-test with level of significance reported as p<.05
** Turidity values are presented in NTU

Figure 12: Temporal Variation of Turbidity among Proctor Creek Water Samples



Analysis of data illustrated in Figure 12 shows a trend in mean turbidity values with the highest turbidity values occurring in May and decreasing throughout the sampling period. Further analysis determined there was no statistically significant temporal variation in turbidity values between sample dates (p=0.45).

Table 11: Analysis of Pearson's correlation between E. coli in water and selected water quality varibles sampled from the Proctor Creek, Atlanta, Georgia, 2014.

	Pearson's R	P-Value*
***E. coli* in water and Turbidity**		
Site 1	-0.42	0.49
Site 2	0.66	0.23
Site 3	0.53	0.35
Site 4	-0.24	0.69
Site 5	0.92	0.03

* Pearson's correlation coefficient with level of significance reported as p< .05

As shown in Table 11, *E. coli* in water was positively correlated with turbidity at site 5 (p=0.03) of Proctor Creek.

CHAPTER V

DISCUSSION

5.1 Major Findings

This study found significant temporal variation in mean *E. coli* concentrations among Chattahoochee water samples between dates 7/10/14 and 6/19/14. Mean *E. coli* counts and mean Dissolved Oxygen values were found to demonstrate variance across sample dates for all sample sites. The USEPA criteria for DO in recreational water are a maintained daily average of 6.0 mg/L and no less than 5.0 mg/L (EPA, 2012). Dissolved Oxygen is important to the health of the Chattahoochee River as it is a critical necessity for the living organisms such as fish, turtles, and other aquatic life inhabiting the River. Changes in oxygen concentration can affect certain species reliant on oxygen-rich water, disrupting the food chain. Dissolved Oxygen has been proven as a useful indicator for water pollution and the effects of urbanization as clearing land and development may send excess organic matter into streams, which uses up oxygen to decompose it (USU, 2015).

In this study, the mean DO values decreased steadily every month with the highest mean value of DO occurring in June and the lowest in September. The seasonal decrease in DO found in this study is concurrent with findings from Breitburg, et al. that determined bottom waters of the Patuxent River are below 50% DO saturations during the summer (2003). This decrease may have been a result of increased temperature throughout the summer months. Increased development can reduce the amount of shaded areas around surface water resulting in temperature increases and DO concentration reduction since warmer water holds less DO than colder (USU, 2015). Although, the relation DO concentration has with *E. coli* counts in this study does not align with the Cheng et al. and

Karn & Harada study, which stated that positive increases in DO promotes the decay of *E. coli* and found trends between increased total coliforms and decreases in DO (Cheng et al., 2013; Karn & Harada, 2001). However, Cheng et al. investigated wetlands consisting of various ponds where sediment and suspended solids have the ability to settle while this study focuses on a flowing river, which may contribute to the varying results (2013). Karn & Harada investigated surface waters, Bagmati and Buriganga, rivers highly polluted by unregulated sewage outfalls; their results indicated a relationship between raw sewage and low DO concentrations. Since the two water treatment plant outfalls on the Chattahoochee River have been proven to have low counts of *E. coli* colonies, the same results cannot be expected in this study. For this reason, DO decrease may be influenced by seasonal changes rather than bacterial increases.

Temporal variation was also found between turbidity values across sample dates for all sample sites; the difference between dates that the lowest and highest mean turbidity values found were also found to be significant. Low river flow usually relates to low turbidity (less than 10 NTU) since increased riverflow often results in turning up sediment and other sediment that result in turbid water (USGS, 2014). This supports the data found in the Chattahoochee River, as dates of recorded low riverflow (7/7/14-7/10/14 and 8/2/14-8/5/14) were also dates low turbidity of the water samples was also recorded (7/10/14 and 8/5/14). A number of studies have shown a strong relationship between indicator bacteria and turbidity measurements (McSwain, 1977; Christensen, 2001; Rasmussen and Ziegler, 2003). Due to findings such as Fries et al. (2006) and Krometis et al. (2007), which reported that 34-42 percent of *E. coli* in surface water samples were attached to particles, a Pearson's correlation was conducted to determine if the two parameters were related. Mean *E. coli* counts and turbidity values were not significantly correlated at any sampling sites. Gregory and Frick (2000) stated that fecal coliform bacteria densities in the Chattahoochee River are highest after rainstorm events when the river is turbid, so the lack of many rain events during the sampling period may have contributed to the low turbidity concentrations.

E. coli concentrations across sites for all sampling dates were similar, but the sampling sites at the Camp Creek Outfall and Douglas County Outfall were lower than other sites. Before the FACD passed in 2003 water treatment effluent was reported to degrade the Chattahoochee River water quality downstream but currently, the mean *E. coli* concentration near the outfalls are lower than other sites. (Clean Water Atlanta, 2010). No significant spatial variation of mean *E. coli* concentration upstream and downstream of the Camp Creek Outfall was recorded, in fact, the lack of significant increases in *E. coli* concentrations downstream of the effluent discharge points to the First Amended Consent Decree (FACD) accomplishing effluent goals (Clean Water Act, 2010; EPD, 1997). The Douglas County Outfall did, however, incur upstream/downstream variations of mean *E. coli* concentrations by three sites, indicating that the water discharged from that outfall may need additional treatment to ensure it does not impair the river's water quality downstream.

Differences between *E. coli* means and MS2 presence and absence were found between the sample date with the lowest *E. coli* concentration (7/10/14) and the date with the highest (6/19/14). The bacteriophage MS2 is a potential indicator of the presence of human viruses in water, meaning that there may be human pathogens in the Chattahoochee River. Yet ANOVA found that the mean concentrations of *E. coli* were similar for sites across all sample dates, regardless of the presence or absence of MS2. This is consistent with a study conduct by Luther and other that found FRNA coliphages were present in significant concentrations although fecal bacteria was low, suggesting that fecal indicator bacteria may not detect viral contamination sufficiently (Luther & Fujioka, 2004).

Similar to the temporal trends of the Chattahoochee River, Proctor Creek experienced higher levels of *E. coli* concentrations and turbidity levels in the early months of sampling, which decreased through September. Consistent with recent studies, such as the Chang et al. research concluding that tributaries influence the water quality of main streams and rivers downstream (Chang, 2005). No statistically significant spatial or temporal variations in turbidity values were found in any of the sample sites or dates of the Proctor Creek but there was significant spatial variation with extremely high spikes in mean *E. coli* concentrations at Site 2 located on Joseph E. Boone. Trends in the concentrations of key variables (turbidity and *E. coli*) were observed but due to the small sample size, no significant results were produced.

Since the Chattahoochee River is a designated recreational water source and Proctor Creek was previously used as a location for recreational activities, it is important to determine how the studied waterways compare to the state of Georgia's recreational water quality standards. EPA water quality standards for *E. coli* in recreational water are categorized by recreational use and human contact. In waterways were people come into full-body contact (FBC) with the water; the single sample maximum of *E. coli* should not exceed 235 CFU/100 mL. If only partial body contact is occurring, then no more than 575 CFU/100 mL of *E. coli* should be present. The Chattahoochee River did not exceed this EPA standard at any of the sampling sites, with the highest count of *E. coli* occurring on 6/19/14 at site six (165.57 CFU/100mL). However, Proctor Creek exceeded the water quality standard at nearly every site on every sampling date. The highest count occurred on 6/24/14 at the Simpson/Boone site (80,735 MPN/100 mL) with the average *E. coli* count for sites over all sampling dates being 6678.8 MPN/100 mL; only four water samples met the Georgia State water quality standard over 11 sampling dates.

5.2 Importance of Study

The health of the Chattahoochee River and Proctor Creek are of great significance to the city of Atlanta, due to the public dependence on both waterways. Since the Chattahoochee River is the main source of drinking water for the state of Georgia, routine monitoring and maintenance is required to ensure health of the consumers. In order to maintain the integrity of the watershed, the federal government has instated regulation to protect both the river's and Proctor Creek's water quality by defining and monitoring definitive water quality standards. The population growth in metro Atlanta has exacerbated the stress the sewer systems were under to accommodate the sanitary sewage and stormwater runoff from impervious surfaces. In fact, before stricter water quality guidelines were instituted, sanitary sewer overflow (SSO) events were quite common. Due to these malfunctions, the city of Atlanta made additional changes to guarantee adequate treatment of wastewater effluent discharged into the Chattahoochee River. Previous studies have focused on point source pollution as the cause of water quality degradation; however currently, nonpoint sources are influencing the health of the urban waterways in Atlanta, which this study will examine. This research is significant, as few investigations have been published regarding the water quality of the Chattahoochee and Proctor Creek.

5.3 Strengths and Limitations

<u>Strengths</u>

To date, there are no studies investigating the current water quality, spatiotemporal variation of *E. coli* and MS2, or the correlation between microbial and pathogenic indicators with certain water quality parameters (DO, riverflow, turbidity) of the Chattahoochee and Proctor Creek.

<u>Limitations</u>

Firstly, this research is comprised of a small sample size of five sampling dates from May to September for the Chattahoochee River samples and eleven for Proctor Creek. Since all data from Proctor Creek was received from the Chattahoochee Riverkeeper database, not all samples were collected consistently so the sampling dates were clustered by month opposed to by date.

5.4 Future Research

Since these waterways must stay within federal and state standards, continuous monitoring should continue but additional sites and sampling dates will improve the amount of statistically significant results. Future research should also investigate the sources of contamination, not only from point sources but also by collecting stormwater runoff from various points to determine where nonpoint source pollution may be in higher concentrations.

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